Radio noise: Global economic and political impact |

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The term *radio* often conjures up images of the early transistor receivers, sound bites from Franklin Roosevelt's inaugural address, and large antenna arrays used for broadcasting. These images do not reflect the modern truth that radios are ubiquitous and constantly employed in everyday life. Some common radios include mobile phones, wireless local area networks (e.g., Wi-Fi) , global positioning systems, satellite radio, Bluetooth, cordless phones, baby monitors, microwave ovens, remote controls, garage door openers, and most devices that are wireless. The recent proliferation of mobile devices and wireless Internet has dramatically increased the amount of electromagnetic energy being broadcast everywhere. This added energy creates noise or, more precisely, interference that can interrupt other signals operating at the same frequency. This noise can worsen analog signals or prevent the reception of digital signals altogether. Within the next five to ten years, the indirect effects of noise will likely result in worldwide decisions to free more bandwidth for mobile and industrial, scientific, and medical applications with an increase in the noise level. The effects of the continued spread of wireless technology may also lead to diverse economic, political, and military issues.

Introduction

Signal interference is one limiting factor in the spread of mobile devices and has recently become a juggernaut in driving economic decisions due the financial value of the billions of mobile phones that have entered the world market in the last 20 years. The shift from one-way communications, like broadcast television, to bidirectional information transmission services, like third generation (3G) cellular telephony, have created major consumer markets and dependence on mobile services.

Consumers are constantly demanding more information at faster rates with better reliability on mobile devices, which continues to increase noise. The demands create social and economic pressures that can drive major policy decisions, like the relicensing of some of the television frequencies for mobile data during the digital television shift in 2007. The already high economic value of the spectrum is projected to experience rapid growth in the next few years.

Communication and noise

Standard electronic communication occurs across a wide range of frequencies in the radio spectrum (i.e., frequencies less than 300 gigahertz) [7]. Typically, communication occurs when a sinusoidal electromagnetic wave, termed a *carrier*, is modulated with an information signal. When communication involves a single carrier frequency, the transmission mode is termed *narrow band* (as opposed to multiple carrier frequencies or wideband), and this is the form of almost every regulated communication currently conducted in the world.

To this end, the radio spectrum is broken into many narrow bands that are then assigned to specific activities such that the physical properties of electromagnetic waves at each frequency (e.g., atmospheric absorption) are suited to the particular communication or industrial use. Broadcasting in narrow bands cannot be perfectly achieved. This can result in some spillover that generates some undesired signal in adjacent bands. These undesirable signals are referred to as *spurious emissions,* and they are a common source of noise.

These communication waves can be interrupted by undesired changes to the signal. This electronic noise is a "random" electromagnetic signal at the frequency of interest that can be caused by natural sources. Noise is more likely due to another party using the same frequency for communication or for intentional jamming; this is typically referred to as *interference.*

While the physics of electromagnetic communication are complex, the basics are fairly analogous to sound. Consider a conference room that represents a single narrow band frequency. Broadcast communications, like television, are similar to a single speaker delivering a lecture in the room. People closer to the speaker will hear well because volume is louder, while listeners toward the rear of the room may miss words or entire sentences. In the same way, radio receivers closer to the station receive a strong clear signal, while distance receivers may have the station drop in and out of reception.

In that same conference room, there may be heating and cooling fans that are running, cell phones ringing, rustling movements and creaking as people adjust their chairs, or a plethora of other sounds. The collection of these sounds interferes with the listener hearing the speaker and represents natural noise sources, like lightning or cosmic radiation. Consider that the

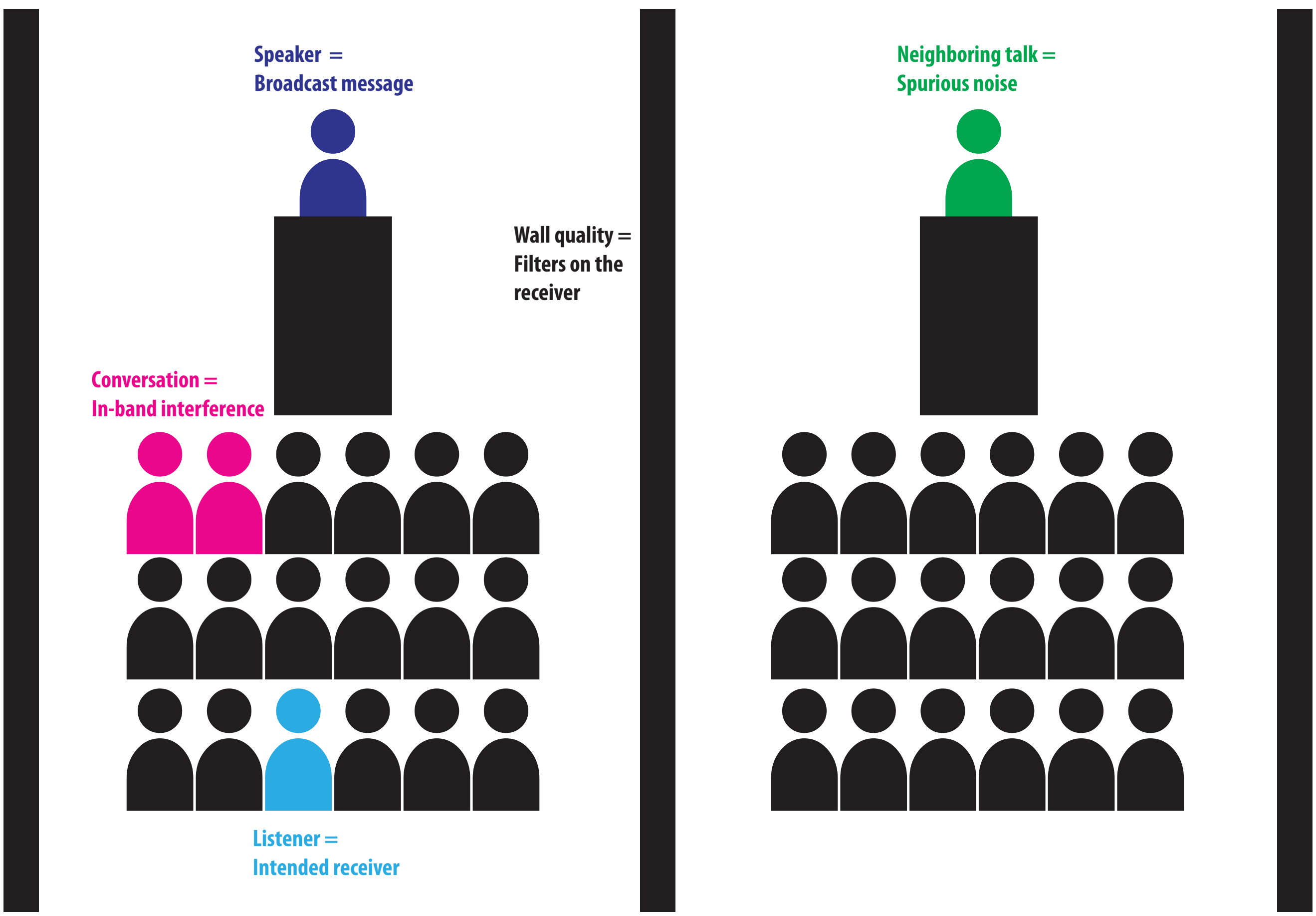

FIGURE 1. Communication across a narrow band frequency (e.g., broadcast television) is similar to giving a lecture in a room of a busy conference center. The speaker (dark blue) is transmitting a broad message to the receiver (light blue). A conversation at the front of the room represents in-band interference (pink). The walls represent the receiver's filter that reduces unwanted signals and prevents spurious noise (green) from adjacent narrow bands.

conference room is actually in a conference center with identical rooms on both sides (see figure 1). In each of those rooms, different speakers are also giving talks, and the walls are poor, allowing sound from their lectures to come into the conference room. The talks coming through the walls are a form of spurious noise, and the quality of the walls themselves represents the quality of the filter on the radio receiver.

Finally, some people are carrying on conversations at the same time that the speaker is talking. If the listener is nearby, the conversations can completely prevent him or her from hearing the talk and represents noise due to in-band interference. If the listener is involved in the conversation and not paying attention to the speaker, the speaker is a source of noise in the conversation. In this way, noise due to interference is completely contextual and depends on the specific communications.

Loosely applying this analogy to real issues can provide some insight into the impact that noise has on the world. Wireless Internet using the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard (i.e., Wi-Fi) typically communicates in the unlicensed industrial, scientific, and medical (ISM) frequency at 2.4 gigahertz (GHz). This is the same frequency that Bluetooth, Zigbee, and a variety of other technologies also use.

Fifteen years ago, there were not many people using wireless Internet, and the data rates were lower than they are today. This is like a conference room with several tables and only a few people scattered throughout, each having quiet conversations with one another with very little difficulty. As time progressed, wireless local area network (WLAN) hot spots were installed in more places, wireless data rates increased, and technologies like Bluetooth began to see regular use. In other words, the conference room started to fill with more people having louder conversations, and some of those conversations were in different languages.

By 2011, the room was extremely crowded with everyone trying to carry on conversations at once. If someone is having trouble communicating in the room, they have three choices. They can: 1) increase their volume, 2) move closer to the other person in the conversation, or 3) move to another room. WLAN users experiencing interference have the exact same three choices. They can: 1) increase the communications power, 2) move closer to the wireless router, or 3) change frequencies. And all three behaviors are commonly seen in response to noise.

Unfortunately, those options are becoming less viable. There are power limits on transmission that prevent the "volume" from constantly increasing, and for practical reasons, one can only be so close or have so many wireless routers. That has historically led to migration to new frequencies (or empty rooms). That option is becoming less viable because technology has now been developed to cheaply utilize frequencies up to 6 GHz with relative ease. Due to the physical properties of electromagnetic waves, this represents the high end of the most desirable mobile frequencies. Basically, all of the conference rooms in the center are now claimed. The full conference center is a condition that will be realized by most urban centers in the world sometime before 2020.

Mobile phones and the ISM bands

The effects of interference that are the most pronounced in the frequency bands are the ones most heavily used. Mobile phone bands and ISM bands are the two sets of applications that are overwhelmed with users and have the greatest driver for increased demand. They are like loud, overcrowded conference rooms with lines at the door. The interference effects in these bands will be used as leverage to shift into other bands (similar to the digital television frequency auctions), and the finances associated with mobile devices will only continue to increase. For this reason, consideration of the future of the spectrum begins with mobile devices and then ISM band applications, like Wi-Fi.

Consumers worldwide are demanding more mobile devices with much greater connectivity. Currently there are approximately 6.8 billion cellular subscribers worldwide with a global shift away from fixed telecommunications infrastructure. In addition to an increasing user base, data demands are also growing. The bandwidth for these communication types will increase by about 100% every 4.4 years. This bandwidth trend is similar to earlier bandwidth gains found in broadband Ethernet and WLAN technologies (see figure 2 on the following page). Additionally, people are migrating from traditional voice and short message service (SMS) communication toward smartphones with significant data demands. By 2015 there will be about 738 million smartphones in use

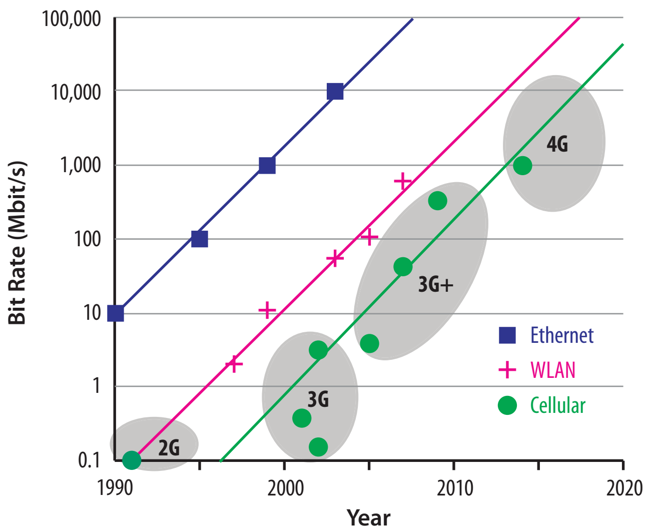

FIGURE 2. Pacific Northwest National Laboratory projects that, like Ethernet and WLANs, the maximum bandwidth for cellular data transmission technologies will increase by about 100% every 4.4 years. [Original figure created by PNNL.]

worldwide. Mobile phones will likely communicate at all ISM frequencies, all cellular frequencies, and all satellite location service frequencies with communication hardware adapting to meet changing standards.

Mobile devices have such a dramatic impact because of the economic value that the carriers can extract. This value drives frequency allocations and subsequently has a dramatic impact on interference. The enormous value of the spectrum coupled with a dramatic increase in demand for wireless data will have several likely effects. The high spectrum value creates inertia in band use by companies already operating in the market. This prevents governments from rapidly changing the purpose of an allocated license because of the extremely negative financial consequences. The same factor drives standardization from the International Telecommunication Union (ITU) for projected available bands that are often released a decade before they are implemented. The last expected outcome is a drastic increase in noise in all licensed communications bands and in all unlicensed ISM bands (e.g., those used for Wi-Fi) [8, 9].

There is a large consumer push to free up unlicensed or ISM bands to allow for free wireless communication instead of paying mobile operators. This creates political pressures because the most commonly used bands fall in the 900 megahertz (MHz) to 5.925 GHz range, which are also coveted by cellular companies [10, 11]. The ISM bands are the most utilized and allow for a wide variety of communication protocols [12–18]. This creates significant additional interference that cannot be as easily compensated for by a single carrier that controls the band. Some forms of ISM usage include WLANs, electronic toll collection, garage door openers, cordless phones, remote controls, Bluetooth, burglar alarms, and microwave ovens. The continued proliferation of ISM band uses is expected to create drastic interference in all current and any new ISM bands that are made available.

Current communication protocols are expected to evolve following historical trend lines. This suggests that the IEEE 802.11ac Wi-Fi standard will be adopted around 2015, Bluetooth will continue to evolve, and ISM bands may be used for wireless high-definition television transmission by 2017. Aside from these protocol improvements, the large driver of future ISM band interference will be information transmission [19–24]. The ISM bands are currently the primary frequencies used for short-range information transfers. Particularly, WLANs are expected to offload Internet traffic from portable devices when available. This has become more prevalent as mobile carriers have moved to pricing schemes in which they charge for data.

Also, the next decade will see an explosion of wireless sensors and supervisory control and data acquisition (SCADA) devices that are expected to use ISM band wireless communication to transmit data to a central node [25, 26]. ISM band noise is expected to be particularly pronounced in urban and developed environments, as these places tend to demonstrate the highest concentration of people and short-range infrastructure and will unlikely change rapidly due to the significant investment manufacturers and network providers have in the current ISM communication protocols.

Other radio uses

There are several other uses of the radio spectrum that do not involve mobile or ISM applications. Several of these applications such as television and radio broadcasting, navigation beacons, aerospace communications, emergency services, and certain military applications are very well regulated and unexpected to see significant changes before 2020. Other traditional radio uses like space-based communication and radio astronomy are more likely to be threatened by the economic emergence of corporations interested in spectrum.

The interference caused by the widespread use of wireless communication has been in constant conflict with radio astronomers who require extremely low background noise to measure anything of significance. This has led to the ITU and most countries adopting passive radio frequency device policies in which limited amounts of spectrum are set aside specifically for radio astronomy [27, 28]. Any interference in these bands is easily detected, and in some areas, the transmitting device is forcibly shut down.

A similar problem occurs with space-based communications, like global positioning system (GPS) signals or satellite radio. The best bands for satellite-to-earth communication are the same bands desired by mobile carriers and ISM band users. Additionally, the atmosphere dramatically attenuates the signal from space. This results in even weak interference being able to prevent communication from satellites; this is highlighted by the accidental jamming of GPS receivers by LightSquared and their fourth generation (4G) mobile communications [29].

In the next five to ten years, the radio astronomy frequencies are expected to remain unchanged, but satellite communications channels will become more crowded as the navigation constellations of Russia (Global Navigation Satellite System, GLONASS), Europe (Galileo), and China (Beidou) all come online [30]. Additionally, amateur satellite bands are also likely to increase in use as private companies continue to develop space transportation.

There are several uses for the amateur and emerging bands aside from satellite communication [31, 32]. They are commonly used by amateur radio operators to attempt to communicate extremely long distances using short waves. Amateurs have been able to communicate using modems as well [33]. There are several other historic and emerging uses for spectrum that are specifically licensed for another application, not licensed at all (i.e., white spaces), or licensed for a new application. These include the numbered radio stations that broadcast patterns that are expected to be used for espionage communications [34–38], ultra wideband communications that communicate by raising and lowering the noise floor, or even high-frequency spectrum used for vehicle-to-vehicle and vehicle-to-road communications. These activities and others are expected to continue to proliferate and operate in segments of the spectrum for specific applications with limited interference from other unlicensed activity.

The exception to this is the expectation that electric grid communication will experience dramatic growth in both deployment and bandwidth within the next few years. Power lines are optimized to transmit high energy levels over long distances and are not designed for communications. As such, high frequencies transmitted along the power lines radiate at similar frequencies, as if being broadcast from an antenna. This is expected to become a significant problem in Europe, where power line Internet is a much larger industry than in other parts of the world. As communication frequencies are increased into the hundreds of megahertz, the radiated power is expected to begin to interfere with several wireless communication technologies in proximity to the power lines [39, 40].

While spectrum usage is expected to continue to expand at a rapid rate, there is no expectation of an increase in health risks. There have been several studies investigating the use of cell phones and potential links to cancer and other wireless health related hazards [41–47]. There is no substantial evidence that wireless devices inherently cause health risks. Research indicates that the greatest personal risk is due to the increase in automobile accidents as a result of distracted driving [48].

Future projections and alternative scenarios

There are two major factors in trend projections of the spectrum. The first factor is the increase in data demand and in the number of devices that communicate wirelessly. This results in an increase in the number of stations and the energy levels necessary to meet increased demand. This factor increases total noise. The second factor is the licensing of more bandwidth to mobile carriers and ISM services. This provides more spectrum to accommodate the demand and results in a decrease in total noise [49]. The most likely noise trends are outlined in table 1 on the following page.

TABLE 1. Noise projections for 2011 through 2020

Year	Total Utilized Bandwidth	Data Demand (norm.)	Data Efficiency	Spectrum Capacity	Hardware Data Gain Needed	Noise Increase
2010	700 MHz	1	1	1	0	0 dB
2011	750 MHz	3	1.26	1.35	2.22	3.45 dB
2012	800 MHz	9	1.59	1.817	4.593	6.57 dB
2013	900 MHz	18	2	2.571	7.001	8.42 dB
2014	1000 MHz	36	2.51	3.586	10.04	9.97 dB
2015	1100 MHz	54	3.16	4.966	10.87	10.33 dB
2016	1200 MHz	81	3.98	6.823	11.87	10.71 dB
2017	1300 MHz	121.5	5.01	9.304	13.06	11.12 dB
2018	1400 MHz	182.3	6.31	12.62	14.45	11.53 dB
2019	1500 MHz	273.4	7.94	17.01	16.07	11.95 dB
2020	1600 MHz	410.1	10	22.86	17.94	12.36 dB

Noise trends suggest that world governments should be expected to increase bandwidth allocated to wireless and ISM services by approximately 850 MHz between 2011 and 2020. It should also be expected that these opened bands (and current wireless and ISM frequencies) will all exhibit noise floors that are approximately 9 decibels (dB) above the 2011 noise floors of the wireless and ISM bands—especially in urban areas.

Assuming these projections are correct, there are also several key scenarios that may be of interest for specific frequencies and applications. The most likely future scenario is made apparent by the accidental jamming of GPS signals. LightSquared technology follows all bandwidth regulations for their spectrum license, but their communications interfere with GPS receivers because those receivers were built with less expensive filters that did not expect, and thus did not block, high energy levels in the adjacent bands. Simply put, the walls between the LightSquared and GPS conference rooms are thin, GPS is quiet, and LightSquared is very loud. Nobody in the GPS room can hear the talk because all they hear is LightSquared. This is not a major problem until other navigation satellites are launched because regulators will prevent LightSquared technology from being implemented if it will hinder satellite navigation. To prevent this, it is recommended that better filters be required on all GPS receivers manufactured from this point forward.

It is important to note that it is impossible to cancel noise in the spectrum. The only way to reduce interference is to prevent transmission in the first place. This creates an interesting scenario in which the only desirable bands (i.e., 500 MHz–5 GHz) that will have very limited interference worldwide will be those set aside for passive radio astronomy. Given the growing dependence on wireless communication for emergency response, interference to wireless communication could become a crippling threat. For this reason, it is expected that several entities may begin to develop secondary communication systems that are capable of operating in these "passive" protected bands, systems that are only activated in an emergency or major conflict.

The desirable mobile bandwidth of the spectrum is already extremely valuable. The economics of licensing, owning, and deploying devices have become influential; corporations ranging from Google to China Mobile significantly impact spectrum allocation decisions worth billions of dollars. The value of the spectrum in the third world is rapidly growing to match the developed world without the corresponding growth in domestic wealth. This could lead to a situation of economic imperialism where developed countries or global companies will be able to purchase huge amounts of spectrum in the developing world and monopolize the communication infrastructure there. Such shifts could generate political leverage in those regions and also create advantages for certain device manufactures that make products for those specific services.

In summary, radio communication has become a vital element of everyday life worldwide. Wireless communication is extremely commonplace and depended upon for a variety of activities ranging from phone communication to finding a restaurant for lunch. Interference noise caused by extensive use of the electromagnetic spectrum is constantly getting worse. This is causing significant economic and political pressures as mobile carriers and ISM band users try to acquire more spectrum to easily handle the greater usage and data rate demands. This is expected to cause an average of 850 MHz of more bandwidth to be allocated for ISM and mobile services worldwide between 2011 and 2020. Current and future frequencies used for consumer applications should still expect an average increase in the noise floor of about 9 dB above 2011 levels, and bandwidth will become so valuable that it will be better to use improved filters in applications like GPS than it is to maintain as much "white space" as is currently allocated to national interests.

About the author

Located in Richland, WA, **Pacific Northwest National Laboratory (PNNL)** is a US Department of Energy (DoE) national laboratory, managed by the DoE's Office of Science and operated by Battelle. PNNL's multidisciplinary scientific teams advance science and technology and deliver solutions to America's most intractable problems in energy, the environment, and national security. PNNL provides world-renowned scientists and engineers, facilities, and unique scientific equipment to strengthen US scientific foundations and advance scientific discovery through innovation.

References

[1] "Wireless personal computing." *Tech Trend Notes.* 1992;1(1):10.

[2] Pinola M. "What is wireless?" 2013. About.com guide [accessed 28 Mar 2013]. Available at: http://mobileoffice.about.com/od/glossary/g/wireless.htm

[3] Ghosh A, Zhang Z, Andrews JG, Muhamed R. *Fundamentals of LTE.* Boston (MA): Pearson Education; 2011. Chapter 1, "Evolution of cellular technologies"; p. 1–44. ISBN-13: 978-0-13-703311-9.

[4] International Telecommunication Union. "The world in 2013: ICT facts and figures." 27 Feb 2013 [accessed 28 Mar 2013]. Available at: http://www.itu.int/ITU-D/ict/facts/material/ICTFactsFigures2013.pdf

[5] "Advanced communications technology." *Tech Trend Notes.* 1992;1(1):7.

[6] "Synchronous Optical Networks (SONET)." *Tech Trend Notes.* 1992;1(2):13.

[7] International Telecommunication Union. *Radio Regulations, Edition of 2004,* Vol. 1. 2004. ISBN: 92-61-10661-7.

[8] International Telecommunication Union. "Frequently asked questions: What is meant by ISM applications and how are the related frequencies used?" Available at: http://www.itu.int/ITU-R/terrestrial/faq/index.html#g013

[9] US National Archives and Records Administration. "Operation in the band 433.5–434.5 MHz." *Code of Federal Regulations.* 47 C.F.R. Sec. 15.240 (2004).

[10] Signal Processing Group, Inc. "The ISM band—A review of the essentials." Available at: http://signalpro.biz/ism1.pdf

[11] Atheros Communications, Inc. "Worldwide Regulatory Progress for Wireless LANs." 2003. Available at: http://wirelesspt.net/arquivos/documentos/chips/Atheros_Regulatory_whitepaper.pdf

[12] Bluetooth. "Specification of the Bluetooth system." 2001;1. Available at: http://www.tscm.com/Bluetooth Spec.pdf

[13] IEEE. "Wireless medium access control (MAC) and physical layer (PHY) specifications for wireless personal area networks (WPANs), IEEE 802.15.1-2005." *IEEE Standard for Information Technology: Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks.* 2005.

[14] Norair JP. "Introduction to Dash7 Technologies." *RFID Journal.* 2009.

[15] OECD Directorate for Science, Technology, and Industry Committee for Information, Computer and Communications Policy. "RFID: Radio frequency identification. OECD Ministerial Meeting on the Future of the Internet Economy." Jun 2008, Seoul, Korea. Available at: http://www.oecd.org/sti/interneteconomy/40892347.pdf

[16] NFC Forum. "NFC activity technical specification." Nov 2010.

[17] Duckworth LL. "Advanced inventory and materials management at Pantex." In: *Proceedings of the 52nd Annual Meeting of Nuclear Materials Management;* Jul 2011, Palm Desert, CA: p. 2270.

[18] Bridgelall R. "Introducing a micro-wireless architecture for business activity sensing." In: *Proceedings of the 2008 IEEE International Conference on RFID;* Apr 2008, Las Vegas, NV: p. 156–164. DOI: 10.1109/RFID.2008.4519344.

[19] Cisco. "Cisco visual networking index: Global mobile data traffic forecast update, 2012–2017." Feb 2012. Available at: http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html

[20] Industry Canada. "SP-5150 MHz—spectrum utilization policy for licence-exempt wireless local area networks in the 5 GHz Range." 2005;2. Available at: http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01158.html

[21] McCann S, Ashley A. Official IEEE 802.11 working group project timelines. 2011 Nov 30. Available at: http://grouper.ieee.org/groups/802/11/Reports/802.11_Timelines.htm

[22] Wi-Fi Alliance. "Wi-Fi certified 802.11n draft 2.0: Longer-range, faster-throughput, multimedia-grade Wi-Fi networks," 2007. Available at: http://www.wi-fi.org/files/kc/WFA_802_11n_Industry_June07.pdf

[23] IEEE. "IEEE P802.11 Wireless LANs specification framework for TGac," 2011. Report No. IEEE 802.11-09/0992r21.

[24] Belanger P. "802.11n delivers better range." 2007 May 31. Wi-Fi Planet TechNet spotlight tutorial. *Wi-FiPlanet.com.* Available at: http://www.wi-fiplanet.com/tutorials/article.php/3680781

[25] Armstrong L, Fisher W. IEEE P802.11—Task group p—meeting update: Wireless accounts in vehicular environments (WAVE). Available at: http://www.ieee802.org/11/Reports/tgp_update.htm

[26] Farber D. [IP] [E-PRIV] [RFID] Dave Emory examines EZ Pass transponders. Interesting-People Message [personal communication]. 2004 Jul 9. Available at: http://www.interesting-people.org/archives/interesting-people/200407/msg00086.html

[27] Miller DF. *Basics of Radio Astronomy for the Goldstone-Apple Valley Radio Telescope.* Pasedena (CA): California Institute of Technology Jet Propulsion Laboratory. 1998. Document No. JPL D-13835.

[28] International Telecommunication Union. "Recommendation ITU-R RA.314-10: Preferred frequency bands for radio astronomical measurements." 2003 Jun. Available at: http://www.itu.int/dms_pubrec/itu-r/rec/ra/R-REC-RA.314-10-200306-I!!PDF-E.pdf

[29] National Coordination Office for Space-Based Positioning, Navigation, and Timing. "LightSquared and GPS." 2012 Sep 25. *GPS.gov.* Available at: http://www.pnt.gov/interference/lightsquared/

[30] Chong C. "Status of COMPASS/BeiDou development." Stanford University 2009 Position, Navigation, & Time Challenges and Opportunities Symposium; Oct 2009; Menlo Park, CA. Available at: http://scpnt.stanford.edu/pnt/PNT09/presentation_slides/3_Cao_Beidou_Status.pdf

[31] International Telecommunication Union. "ITU radio regulations—article 1, definitions of radio services." 2012 Oct 24. ICT Regulation Toolkit. Available at: http://www.ictregulationtoolkit.org/en/PracticeNote.2824.html

[32] Baruah S (VU2MUE, formally VU2MSY). "Frequency allocation to Amateur Radio Services." 2005 Jan 14. QSL.net. Available at: http://www.qsl.net/vu2msy/FREQ.htm

[33] Applegate AR. "A little amateur history." 2012 Dec 26. K0BG.com. Available at: http://www.k0bg.com/history.html

[34] Mäkeläinen M. "Monitoring Iraq: War of the airwaves." 2003 Feb 24. DXing.info. Available at: http://www.dxing.info/articles/iraq.dx

[35] Universal Radio Research. "Clandestine radio." 2003. DXing.com. Available at: http://www.dxing.com/clandest.htm

[36] Irdialani Limited. "The Conet project 1111: Recordings of shortwave numbers stations." 2012. Irdial-Discs. Available at: http://www.irdial.com/conet.htm

[37] Priyom.org [home page]. Available at: http://www.priyom.org/

[38] Sokol B. "Espionage is in the air." *Miami New Times.* 2001 Feb 8. Available at: http://www.miaminewtimes.com/2001-02-08/news/espionage-is-in-the-air/

[39] AMSAT: The Radio Amateur Satellite Corporation [home page]. Available at: http://www.amsat.org/amsat-new/

[40] Richards JC , Williams JV. "Potential interference from broadband over power line (BPL) systems to federal government radiocommunication systems at 1.7–80 MHz," 2007. National Telecommunications and Information Administration. NTIA Report 08-450.

[41] Lahkola A, Salminen T, Raitanen J, Heinävaara S, Schoemaker MJ, Christensen HC, Feychting M, Johansen C, Klaeboe L, Lönn S, Swerdlow AJ, Tynes T, Auvinen A. "Meningioma and mobile phone use—a collaborative case-control study in five North European countries." *International Journal of Epidemiology.* 2008;37(6):1304–1313. DOI: 10.1093/ije/dyn155

[42] Inskip PD, Hoover RN, Devesa SS. "Brain cancer incidence trends in relation to cellular telephone use in the United States." *Neuro-Oncology.* 2012;12(11):1147–1151. DOI: 10.1093/neuonc/noq077

[43] Khurana VG, Teo C, Kundi M, Hardell L, Carlberg M. "Cell phones and brain tumors: a review including the long-term epidemiologic data." *Surgical Neurology.* 2009;72(3):205–214. DOI: 10.1016/j.surneu.2009.01.019

[44] Sakurai T, Kiyokawa T, Narita E, Suzuki Y, Taki M, Miyakoshi J. "Analysis of gene expression in a human-derived glial cell line exposed to 2.45 GHz continuous radiofrequency electromagnetic fields." *Journal of Radiation Research.* 2011;52(2):185–192. DOI: 10.1269/jrr.10116

[45] Gerner C, Haudek V, Schandl U, Bayer E, Gundacker N, Hutter HP, Mosgoeller. "Increased protein synthesis by cells exposed to a 1,800-MHz radio-frequency mobile phone electromagnetic field, detected by proteome profiling." *International Archives of Occupational and Environmental Health.* 2010;83(6):691–702. DOI: 10.1007/s00420-010-0513-7

[46] Diem E, Schwarz C, Adlkofer F, Jahn O, Rüdiger H. "Non-thermal DNA breakage by mobile-phone radiation (1800 MHz) in human fibroblasts and in transformed GFSH-R17 rat granulosa cells in vitro." *Mutation Research-genetic Toxicology and Environmental Mutagenesis.* 2005;583(2):178–183. DOI: 10.1016/j.mrgentox.2005.03.006

[47] Lerchl A, Wilhelm AFX. "Critical comments on DNA breakage by mobile-phone electromagnetic fields." *Mutation Research-genetic Toxicology and Environmental Mutagenesis.* 2010;697(1–2): 60–65. DOI: 10.1016/j.mrgentox.2010.01.010

[48] Watkins ML, Amaya IA, Keller PE, Hughes MA, Beck ED. "Autonomous detection of distracted driving by cell phone." In: *Proceedings of the 14th International IEEE Conference on Intelligent Transportation Systems;* Oct 2011; Washington, DC; p. 1960–1965. DOI: 10.1109/ITSC.2011.6083026

[49] International Telecommunication Union. "Estimated spectrum bandwidth requirements for the future development of IMT-2000 and IMT-Advanced," 2006. Report ITU-R M.2078.